Cyber Enabled Radio Astronomy: Synthesis Imaging of the Universe

David M. Halstead, CIO, NRAO

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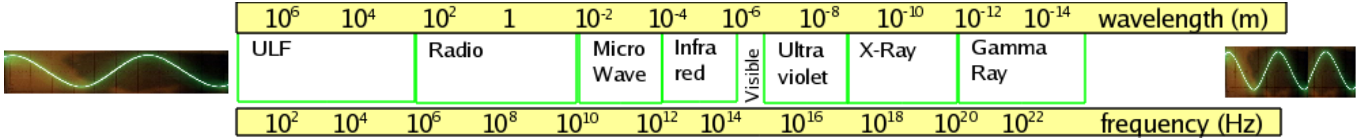
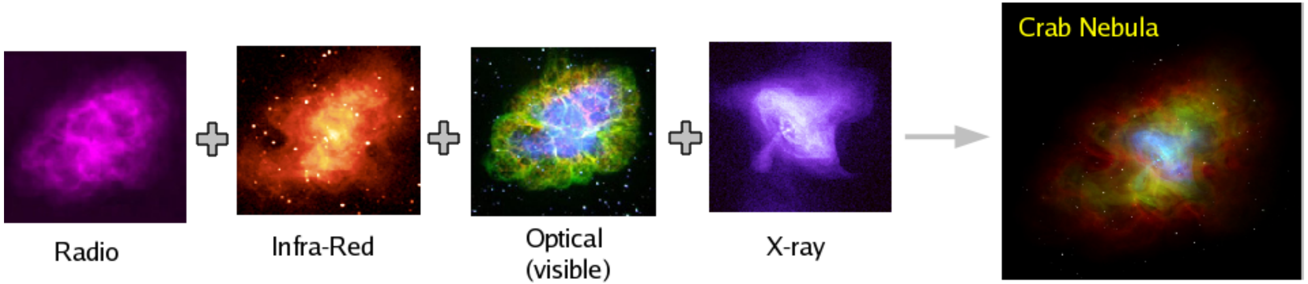
VLA: Very Large Array

ALMA: Atacama Large mm/sub mm Array

The Electromagnetic Spectrum



Objects can look different at different wavelengths (colors vs. shades of grey)



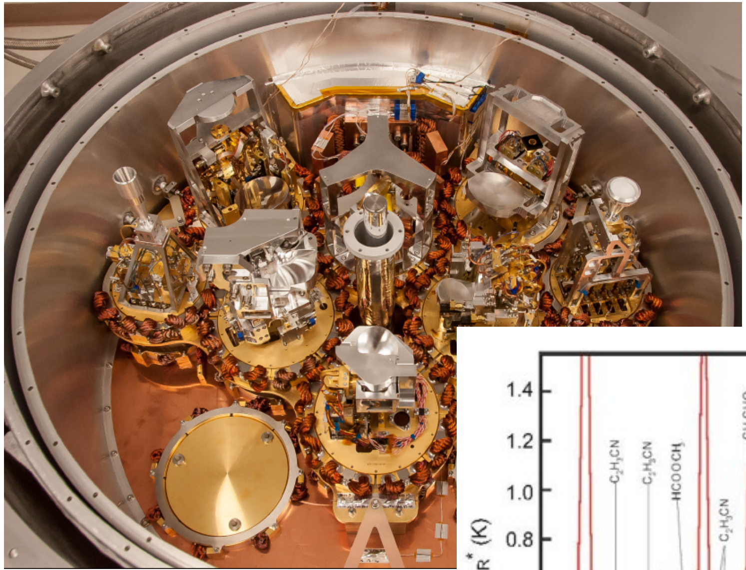
We want to image at all wavelengths

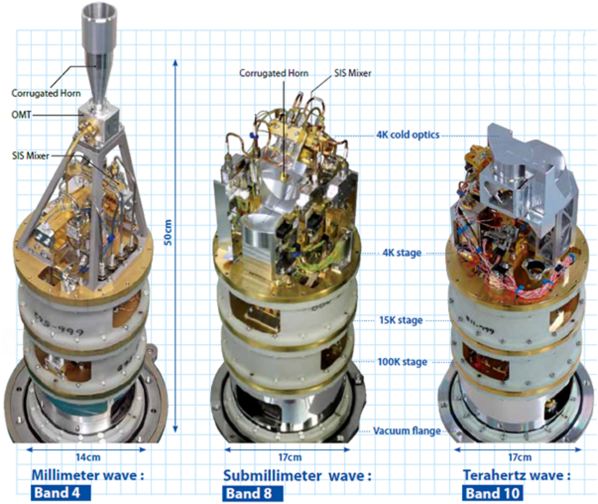
..... with the same level of detail

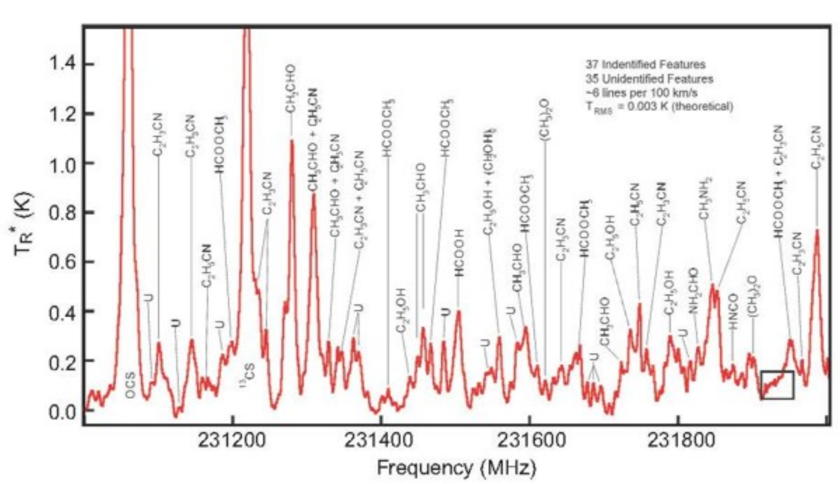
How do we detect radio waves?

OR….

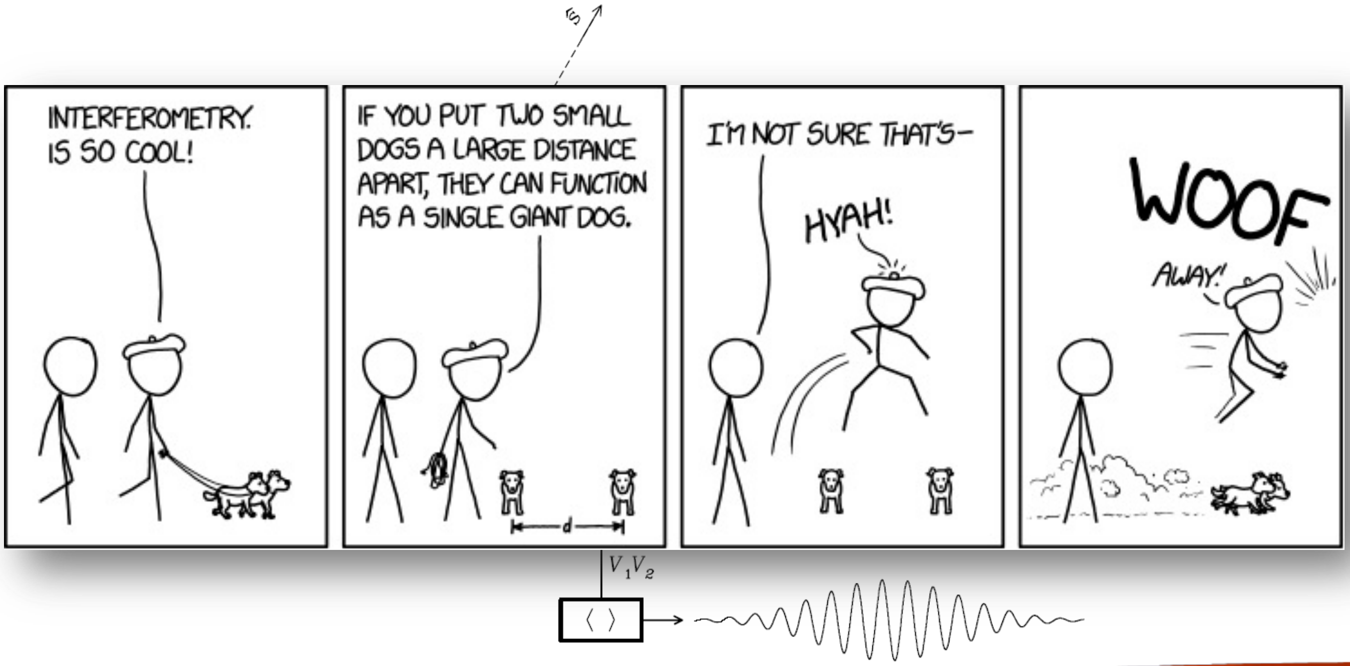
Use single pixel "cameras" on many antennae



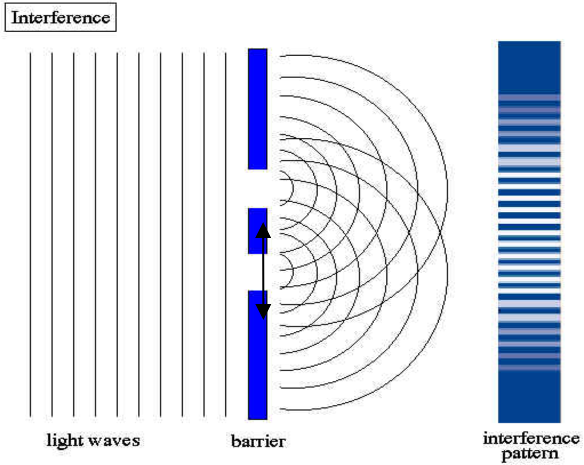




Radio Interferometry: Relies on pairs of antennae to emulate a much larger dish

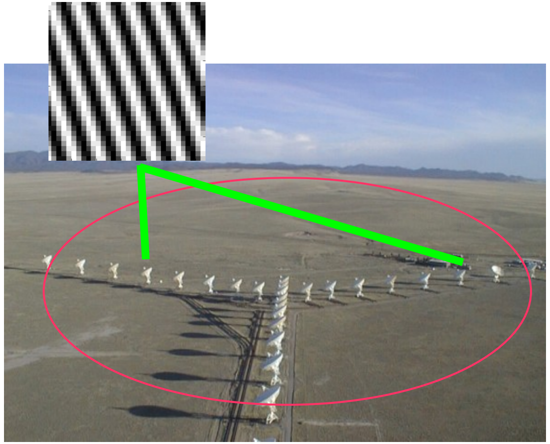


Measure interference fringes



Young's Double-Slit Experiment

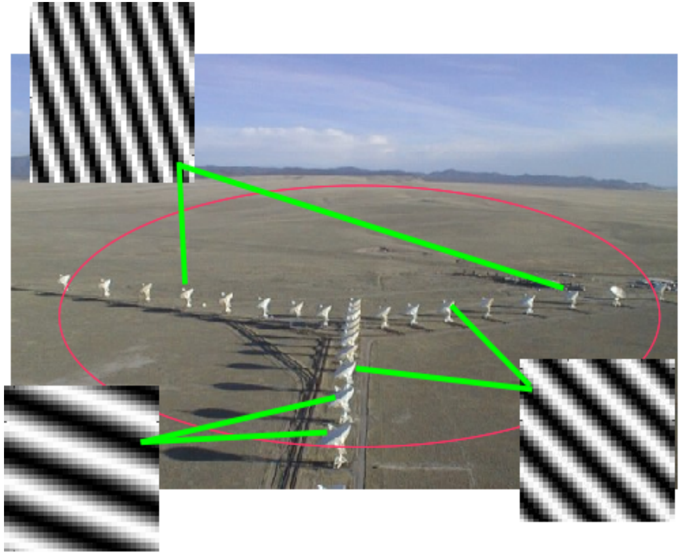
Distance between slits controls the wavelength of interference fringes



One dish == One slit

=> Each pair of antennas captures a different 2D fringe.

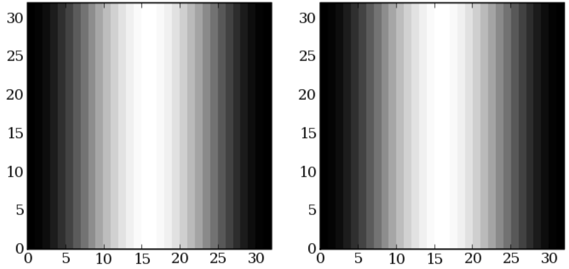
Image Formation



Build an image by combining all measured fringes.

2D Fourier transform :

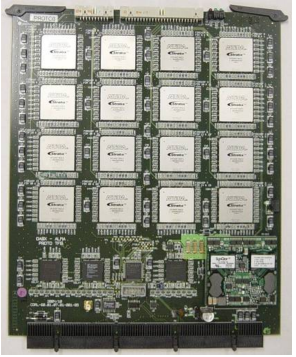
Image = sum of cosine 'fringes'.



ALMA Correlator: HPC@ 16,200 feet

Correlator Quadrant

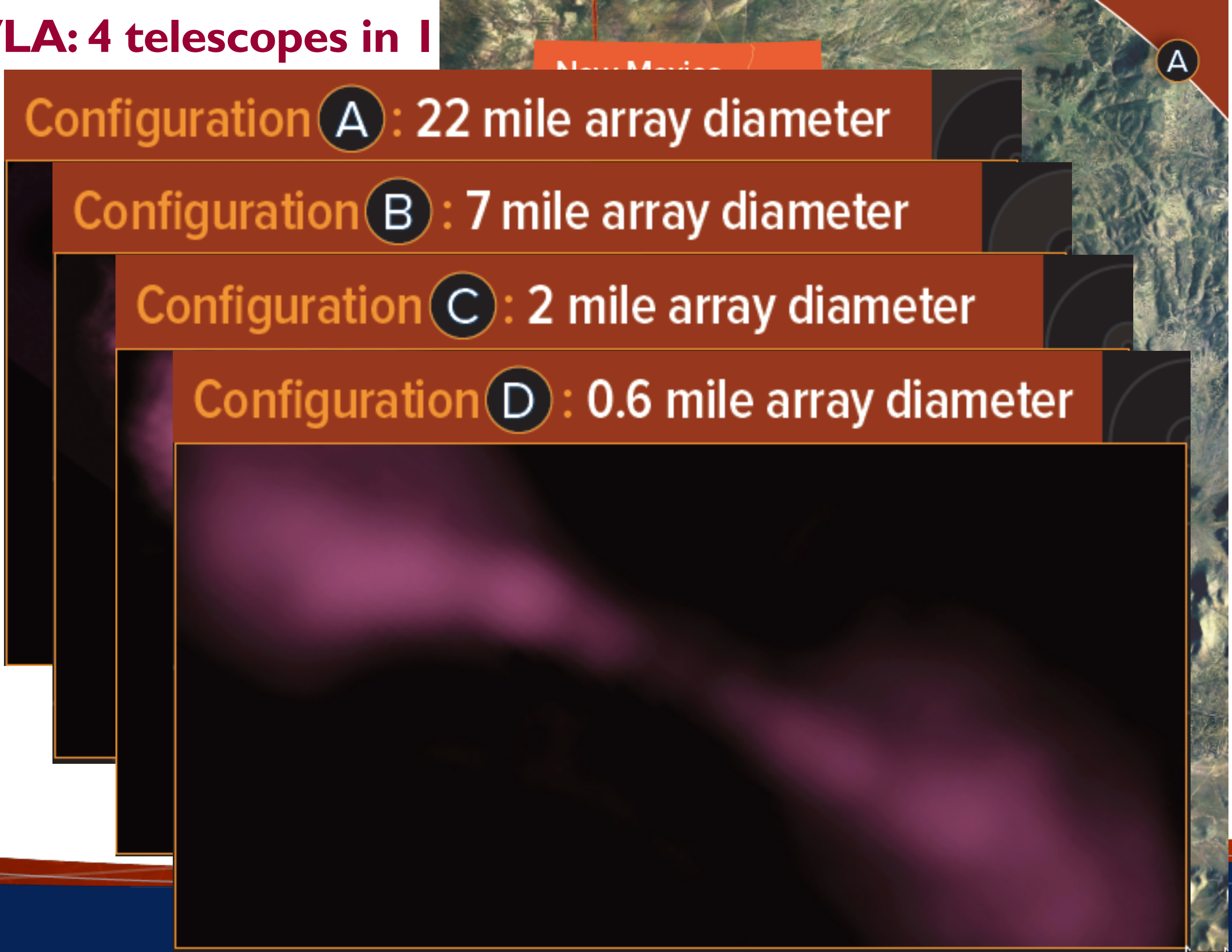
Tunable Filter Bank Card



- Receives signals from 50x12m antennae
- 2551 printed circuit boards total in system
- 8192 Altera Stratix II FPGAs on TFB cards
- 32768 custom correlator chips with 4096 processors for multiply-and-add calculations
- Cross-correlation rate 17 Peta ops/sec
- Output specified at 6-60MBytes/sec

Correlator Card

VLA: 4 telescopes in 1



Radio Galaxy Hercules A, powerful jets of sub-atomic particles blast 500,000 Light-years into space powered by a massive black hole

What’s Next?

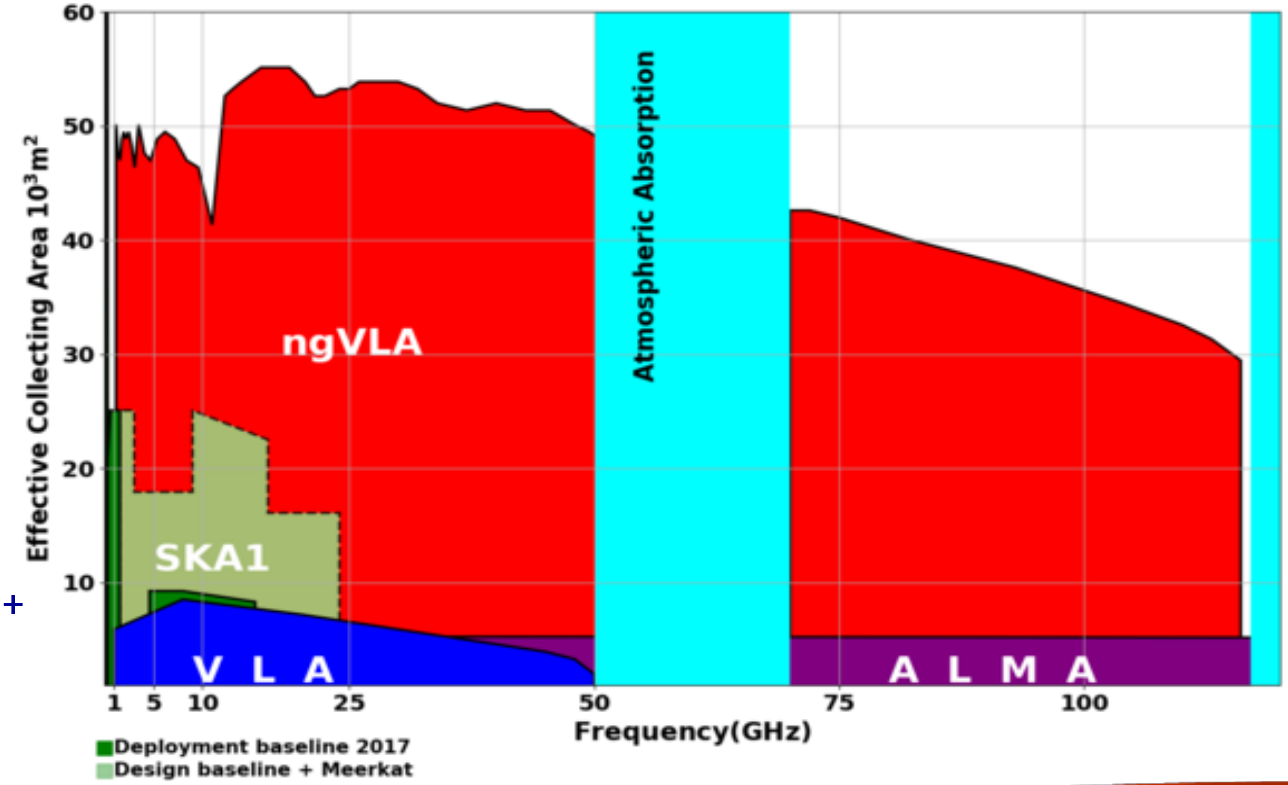
ngvla

Next Generation Very Large Array

- **1.2 - 116 GHz** Frequency Coverage
- **Short Baseline Array**: 19 x 6m offset Greg. Antenna
  - Use 4 x 18m in TP mode to fill in (*u, v*) hole
- **Main Array**: 214 x 18m offset Gregorian Antennas
  - Fixed antenna locations across NM, TX, AZ, MX.
- **Long Baseline Array**: 30 x 18m antennas located across continent for baselines up to 8860km

Band #	Dewar	f_L GHz	f_M GHz	f_H GHz	f_H: f_L	BW GHz
1	A	1.2	2.35	3.5	2.91	2.3
2	B	3.5	7.90	12.3	3.51	8.8
3	B	12.3	16.4	20.5	1.67	8.2
4	B	20.5	27.3	34.0	1.66	13.5
5	B	30.5	40.5	50.5	1.66	20.0
6	B	70.0	93.0	116	1.66	46.0

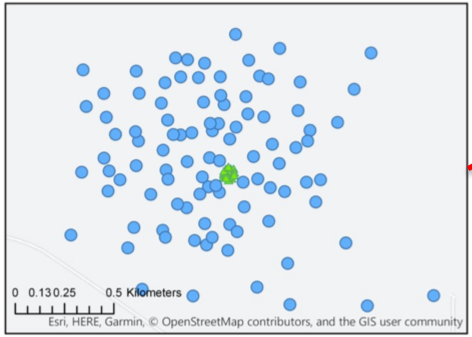
It's all about sensitivity and bandwidth

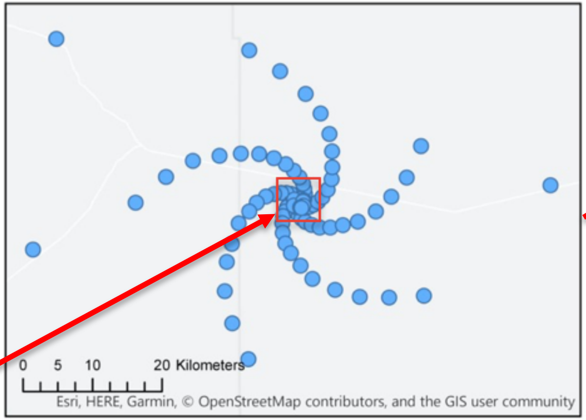


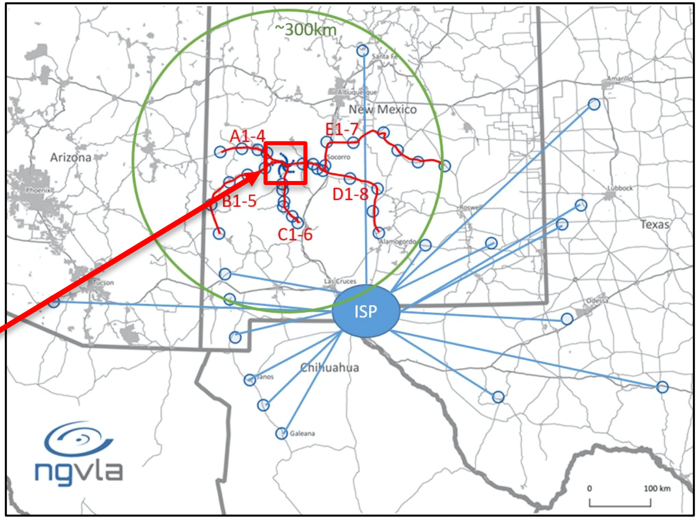
244x18m dishes +
19x6m dishes

Main Array Configuration

Radius	Collecting Area Fraction
0 km < R < 1.3 km	44%
1.3 km < R < 36 km	35%
36 km < R < 1000 km	21%



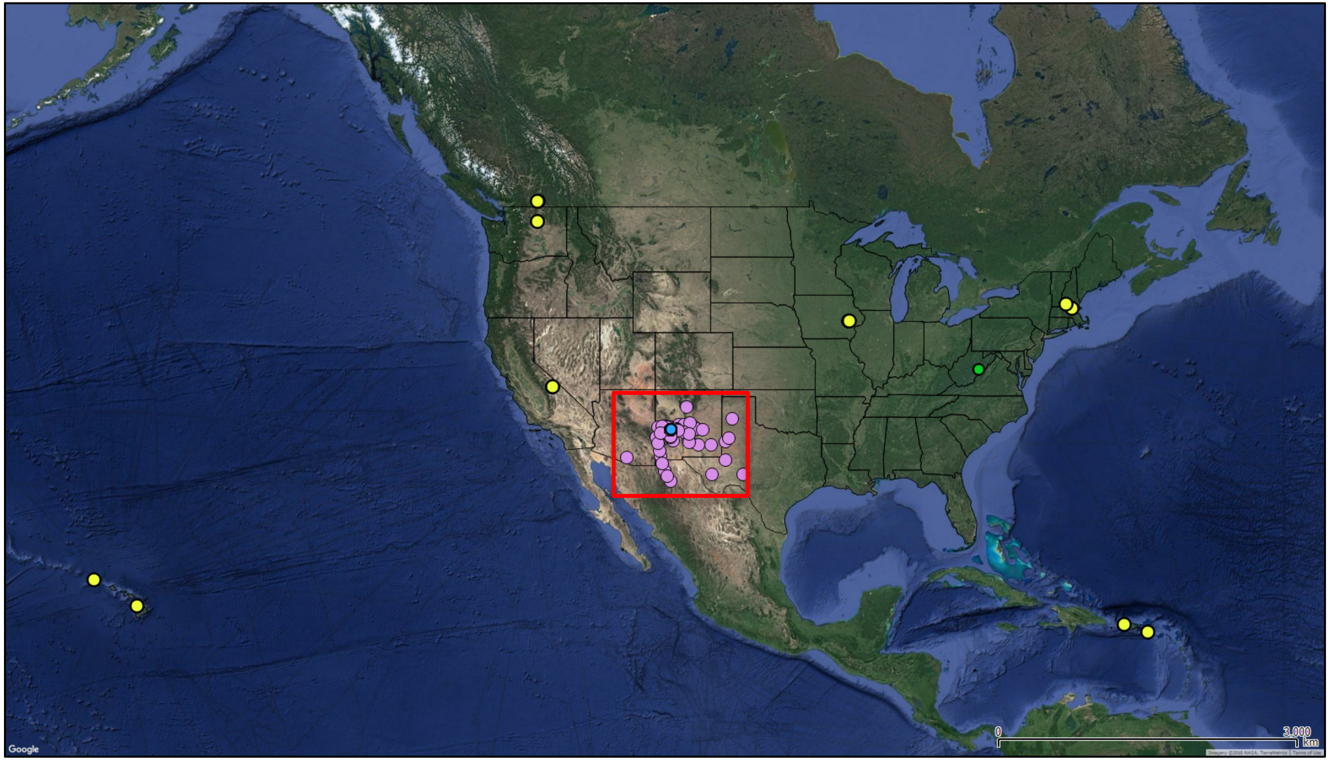




Long Baseline Array (LBA)

- 30 x 18m Antennas at 10 sites
- Balance between Astrometry & Imaging Use Cases

Qty	Location	*Possible* Site
3	Puerto Rico	Arecibo Site
3	St. Croix, US VA	VLBA Site
3	Kauai, HI	Kokee Park Geo. Obs.
3	Hawaii, HI	New Site (off MK)
2	Hancock, NH	VLBA Site
3	Westford, MA	Haystack
2	Brewster, WA	VLBA Site
3	Penticton, BC, CA	DRAO
4	North Liberty, IA	VLBA site
4	Owens Valley, CA	OVRO



Challenges/Opportunities

- Each dish generates up to 320 Gbps of uncompressible data
- We require time sync of ~70fs over ~10,000 km
- All signals must get back Exa-Scale correlator within ½ a second
- The output of the correlator reaches 80Gbps (~600TBytes/day)
- PI access to PetaScale CI resources needing ~30k Cores
- On demand data reduction, imaging, and facilitated collaboration

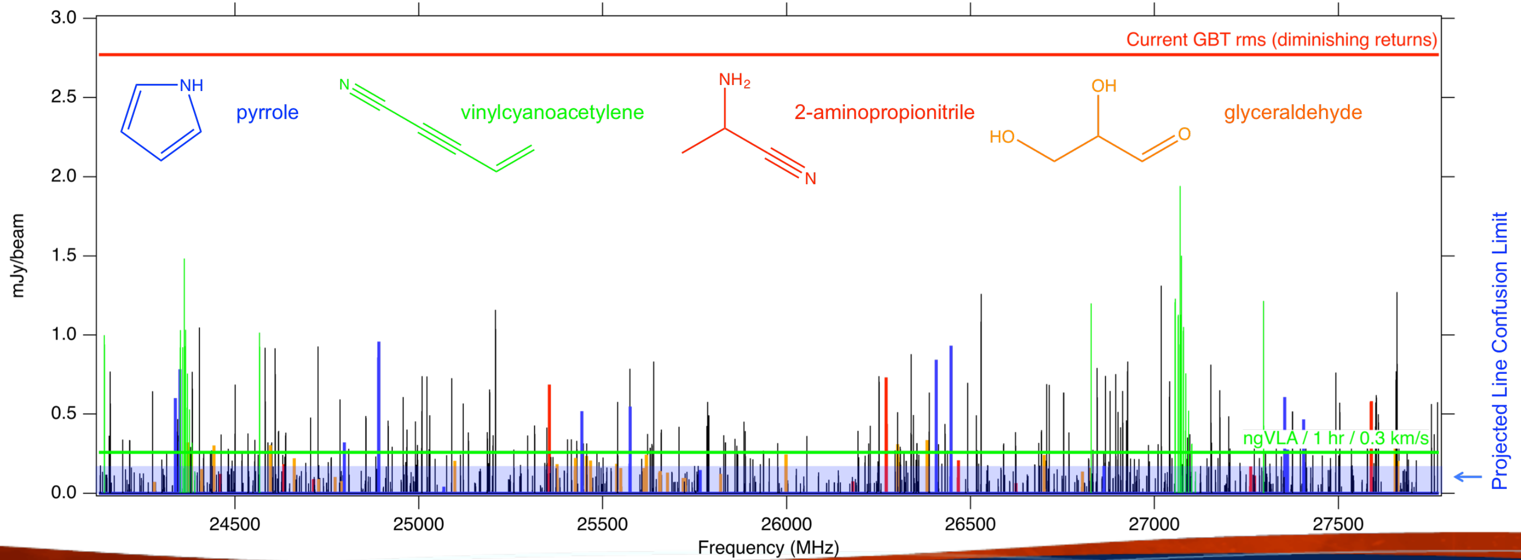
- **Image Exoplanets!**

Questions?

ngVLA.nrao.edu

Contact Info: dhalstead@nrao.edu

SPIE ngVLA technical overview: https://arxiv.org/pdf/1806.08405



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